AD-763 724

AMPLIFICATION OF LOW LIGHT LEVEL OPTICAL SIGNALS BY PREFERENTIAL INTEGRATION IN IMAGING TUBES

Jacob Rotstein, et al

Massachusetts Institute of Technology

Prepared for:

Advanced Research Projects Agency

12 June 1973

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

AD 765724

Technical Note 1973-24

J. Rotstein
J. W. Bielinski

Amplification of Low Light Level Optical Signals by Preferential Integration in Imaging Tubes

12 June 1973

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA – R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

Lincoln Laboratory, M. I. T.

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

Amplification of Low Light Level Optical Signals by Preferential Integration in Imaging Tubes

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Note

5. AUTHOR(S) *(Last name, first name, initial)*

Rotstein, Jacob and Bielinski, Joseph W.

6. REPORT DATE

12 June 1973

7a. TOTAL NO. OF PAGES

~~36~~ 39

7b. NO. OF REFS

5

8a. CONTRACT OR GRANT NO. F19628-73-C-0002

b. PROJECT NO. ARPA Order 600

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

Technical Note 1973-24

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

ESD-TR-73-171

10. AVAILABILITY/LIMITATION NOTICES

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

None

Details of illustrations in this document may be better studied on microfiche.

12. SPONSORING MILITARY ACTIVITY

Advanced Research Projects Agency, Department of Defense

13. ABSTRACT

A preferential integration technique is described which permits the selective amplification of low light level signals with a simultaneous suppression of bright signals, optical backgrounds and tube dark currents. This unique technique extends the "in frame" dynamic range of imaging tubes by over one magnitude with a significant improvement in the threshold sensitivity. Preferential integration permits handling signals as weak as a 0.05 signal to peak-to-peak noise ratio. Improvements of the tubes' modulation transfer function is a direct consequence of the increase in the signal to noise ratio and the suppression of dark levels. The preferential integration technique is applicable to all types of electron beam scanning imaging tubes.

14. KEY WORDS

optical signals — preferential integration technique — imaging tubes

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

AMPLIFICATION OF LOW LIGHT LEVEL OPTICAL SIGNALS BY PREFERENTIAL INTEGRATION IN IMAGING TUBES

JACOB ROTSTEIN

J. W. BIELINSKI

Group 52

TECHNICAL NOTE 1973-24

12 JUNE 1973

LEXINGTON MASSACHUSETTS

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology. This work was sponsored by the Advanced Research Projects Agency of the Department of Defense under Air Force Contract F19628-73-C-0002 (ARPA Order 600).

ABSTRACT

A preferential integration technique is described which permits the selective amplification of low light level signals with a simultaneous suppression of bright signals, optical backgrounds and tube dark currents. This unique technique extends the "in frame" dynamic range of imaging tubes by over one magnitude with a significant improvement in the threshold sensitivity. Preferential integration permits handling signals as weak as a 0.05 signal to peak-to-peak noise ratio. Improvements of the tubes' modulation transfer function is a direct consequence of the increase in the signal to noise ratio and the suppression of dark levels. The preferential integration technique is applicable to all types of electron beam scanning imaging tubes.

Accepted for the Air Force
Joseph J. Whelan, USAF
Acting Chief, Lincoln Laboratory Liaison Office

TABLE OF CONTENTS

AMPLIFICATION OF LOW LIGHT LEVEL OPTICAL SIGNALS
BY PREFERENTIAL INTEGRATION IN IMAGING TUBES

I. INTRODUCTION

Electron beam scanning tubes were primarily developed for the TV entertainment field with their design features and performance characteristics optimized for that application. The spectral sensitivity of the most common tubes, like image orthicons, vidicons, and plumbicons coincides roughly with the response of the human eye, and scanning rates are chosen to provide flicker free viewing. The incorporation of signal integration into the tube's mode of operation yields high sensitivity, permitting the broadcasting of scenes with relatively low or moderate illumination. Modified versions of electron beam scanning tubes have found application in different electro-optical systems having little in common with commercial TV. The spectral sensitivity has been extended into the high energy photon region, including X-ray radiation, on one side of the visible range and into the long wavelength region including infrared radiation, on the other side. Special applications triggered the development of more exotic tubes having extremely high sensitivity and other desired features. What is interesting to note however is the fact that usually the system designers have been rather conservative in their methods of tube operation and have deviated very little from the TV standards. Of course, some systems were built with different frame and scan rates but those changes can be classified as modifications to the standard mode of tube operation and not a new technique. In this report some non-conventional modes of operation of electron beam scanning tubes will be described which enhance their performance for some special applications and even extend their operational range outside of the present limits.

II. PRINCIPLE OF OPERATION OF IMAGING TUBES

A brief review of the principles of operation of imaging tubes will be helpful in understanding the new techniques. For an "in depth" study of imaging tubes, information can be found in the references listed in this report.[1-5]

The basic construction of an electron beam scanning tube consists of a vacuum tight envelope in which three major components are present. The front end of the tube, usually called the image section, transforms the optical image into an electrical charge pattern. The second element is the electron readout beam which scans the charge pattern in a raster mode, senses the stored charge, and delivers the output video signal. The electron optics which focuses and guides the electron beam is the third element of the tube. This general description covers all of the modern types of tubes. The differences between various tubes occur in the way the optical image is sensed, the electrical charge is stored and the method of readout by the electron beam. In the vidicon tube, e.g., the photoconductive retina acts both as an optical sensor, and a charge storage media. However in tubes utilizing photoemissive layers as the optical sensor, e.g., image orthicons and image isocons, the charge is stored on a separate high resistivity membrane. In all types of tubes the positive charge stored on the target is neutralized by deposition of electrons from the scan beam and the number of electrons required for this process determines the amplitude of the video output signal. The video information from the electron beam can be transferred to the first amplification stage in different ways depending upon the tube's construction. In imaging tubes with the so-called "direct readout" the electron beam, scanning over a resolution element, deposits charges and a corresponding pulse in the signal plate constitutes the video output. From there, the video is

amplified for further processing. The noise in this type of system, is determined primarily by the preamplifier noise which, to a first approximation, is independent of the signal amplitude. The direct readout beam method is used in vidicon, silicon intensifier target (SIT) and intensified SIT (ISIT) tubes.

In the "return beam" readout mode, used in image orthicon, isocon, and special vidicon tubes, the video signal is derived from the modulation of the electron beam returned from the target. In the orthicon this method of readout produces a negative picture because it represents that fraction of the incident beam which is not used for the charge neutralization on the target. This situation is easily corrected by the incorporation of an inverting stage in the electronic chain. The advantage of the returned beam method is that low noise amplification is obtained by incorporating an electron multiplier into the tube structure.

A relatively recent modification of the return beam readout is used in the image isocon tube. The electrons contained in the return beam originate from two processes. The reflected beam consists of electrons which do not land on the target and return in a path directly related to that of the primary beam. In the isocon these electrons are guided by the electron optics through the aperture in the first electron multiplier's dynode and do not contribute to the tube's output signal. The second category of electrons, from which the video signal is derived, are those scattered from the target. These travel a different path and only they are permitted to enter the electron multiplier. The number of scattered electrons from a given resolution element is proportional to the charge stored on this area and therefore is a direct measure of its light exposure. The use of the scattered electrons for video readout improves the sensitivity and extends the dynamic range of the

image isocon tube over the orthicon tube.

The high sensitivity of the scanning beam imaging tubes is attributed to their signal integration capability. A schematic drawing of a vidicon tube is shown in Fig. 1.[1] Figure 2 represents an equivalent circuit of a vidicon tube. A hypothetical resolution element can be represented by a resistance "R" whose value is a function of the light intensity, and a capacitance "C" representing the storage capability. The electron beam in its travel over the target returns to the same spot once every "frame time". During the dwell time on the resolution element, the beam charges capacitor C to the cathode potential, and at the same time a video signal proportional to the charge deposited appears across the resistor R_L. During the time interval between beam landings the capacitor C loses some of its charge through the resistor R. The degree of the discharge is determined by the resistance value R and the "frame time." The typical relation $Q = f(t)$, for a vidicon tube, is an exponential function and is shown in Fig. 3. The curves 1, 2, 3, and 4 represent the discharge rate of the element of the target for different light levels. Curve 1 corresponds to the lowest illumination used, and curve 4 the highest one. For a single frame duration represented by point B on the time axis and illumination level corresponding to curve 1, the tube's output will be proportional to the discharge represented by the length ℓ-K. Of special interest are curves 3 and 4. Curve 3 intercepts the time axis at time B, which means that the retina element is completely discharged and the electron beam has to deposit the Q max. charge, on the retina.*

---

*Being exponential functions, the curves should run asymptotic to the time axis. However, for all practical purposes it can be assumed that they reach the time axis within a finite time.

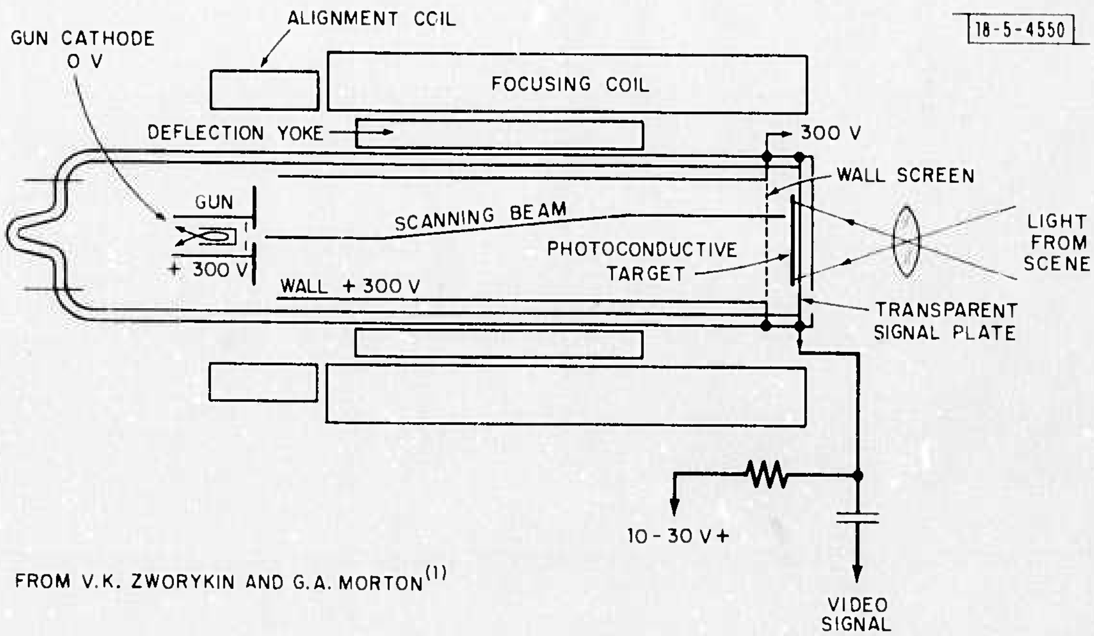


Fig. 1. The "vidicon" photoconductive pickup tube.

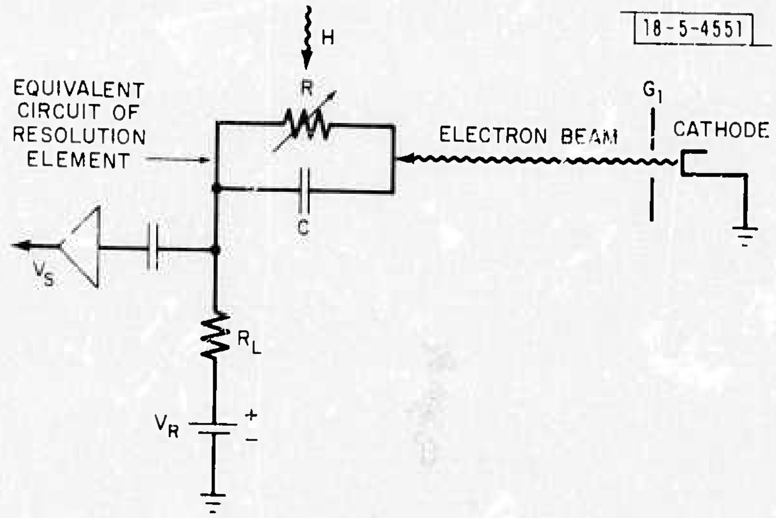


Fig. 2. Equivalent circuit of a vidicon tube.

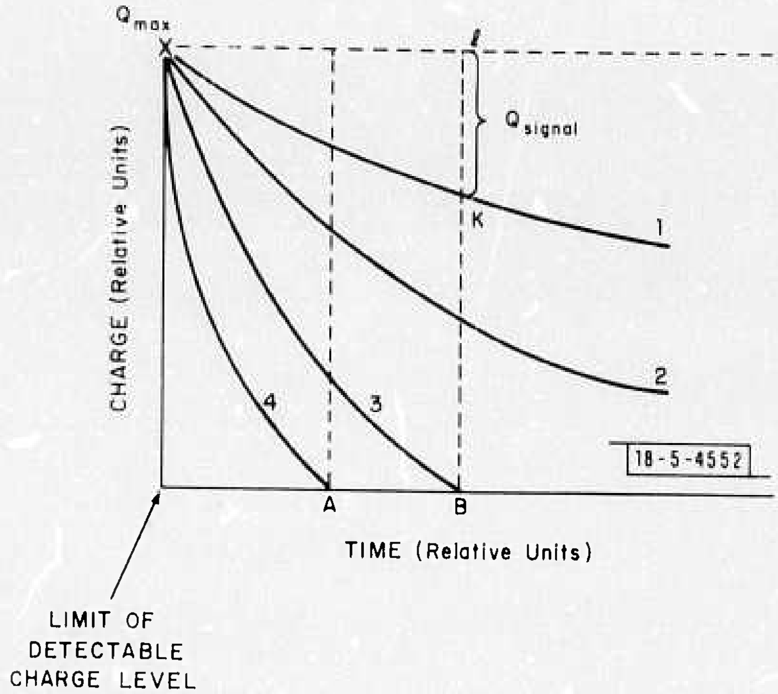


Fig. 3. Discharge rate of a vidicon target as a function of time.

This condition corresponds to the highest optical signal intensity which this tube at this frame rate is able to handle. The tube output for curve 4 will be the same as for curve 3 because in both cases the electron beam has to restore the full charge, Q max. The only difference between curves 3 and 4 is that the illumination corresponding to the latter curve was so intense that the resolution element fully discharged in a fraction of a frame time.

This analysis of Fig. 3 leads to an important characteristic of the imaging tubes, namely the transfer function which is shown in Fig. 4. Some points on this curve are of particular interest in describing the tube characteristic. Point M on this curve represents the, often quoted, threshold sensitivity of the tube. The tube's threshold sensitivity, the noise equivalent irradiance (NEH), is defined as the irradiance on the retina which yields a signal equal to the peak-to-peak noise at the system's output. The NEH expression is used for resolved images and is measured in watts/cm^2. For unresolved images the NEP (noise equivalent power) value is used, and is expressed in watts/resolution element. The irradiance range between point M and point B is the operational range of the tube, and is referred to as the "in frame dynamic range." The function $V_s = f(H)$ in this range is usually a straight line in log-log coordinates. In this irradiance range the resolution capability of the tube remains relatively constant and no image "spreading" or "blooming" takes place. Point "B" in Fig. 4 corresponds to the irradiance value shown in Fig. 3 as curve 3. A similar analogy exists between point "A" on Fig. 4 and curve 4 in Fig. 3. As was mentioned previously, the signal output from the electron tube will be the same for irradiances of "A" and "B" except that at exposure "A", the tube is overloaded. Operation of the tube under those conditions causes a loss in resolution and, in

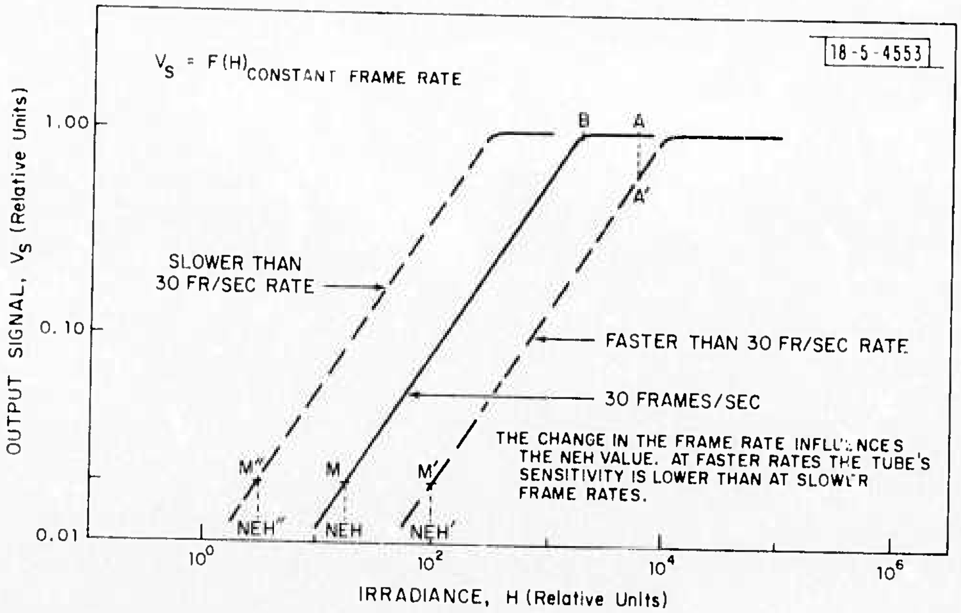


Fig. 4. Variations of the tube's transfer function with frame rate.

extreme cases, even permanent target damage.

For broadcasting applications a rate of 30 frames/sec is chosen to prevent the flicker sensation experienced by the human eye at lower frame rates. However, in the design of detection systems more flexibility is available in the choice of frame rates. Let us now assume that it is important to be able to measure irradiances of the order of value "A". To achieve this goal, the frame rate of the system could be increased, and this change would shift the transfer function to the right as shown in Fig. 4 as the dashed curve. This transfer towards shorter frame times decreases the tube's sensitivity but puts the irradiance "A" in the operational range of the tube. However, a limit is imposed on the reduction of the frame duration by the system's bandwidth, and for tubes with electromagnetic beam deflection by the horizontal sweep rate. It seems that 100 frames/sec with 525 lines/frame is presently an operational limit.

In the presence of bright stars or high level optical background in the camera's field-of-view (FOV) even this short single frame integration can be excessive causing saturation of the image tube. A technique has been developed which permits shortening the integration time by reducing the scanned area of the target. With this mode of operation, the frame and scan line rates are set to the maximum, e.g., 100 frames/sec and 525 lines/frame. The vertical sweep is modified in such a manner that after scanning a preset number of horizontal lines, the beam returns to the beginning of the undersized frame. In the above mentioned 100 frames/sec and 525 line rate, scanning only one fifth of the raster height with 100 lines would shorten the integration time by a factor of five. This technique is applicable only to imaging tubes which are not sensitive to "raster burn-ins." We performed our test on silicon diode

vidicon tubes without any adverse effects. A decrease in the frame rate, which is equivalent to a longer integration time, would have the opposite effect. The transfer function would be shifted to the left and the system's sensitivity would be increased. There is however a practical limitation which restricts the "adaptability" of the system to cover low level irradiances. The threshold sensitivity of any electro-optical system is ultimately limited by its dark current and internal noise level. The variation of the operational range of the tube by controlling the integration time does not, however, change the dynamic range. It covers an optical signal spread of 30 for the Image Orthicon, and up to 100 for the vidicons.

The construction of the image orthicon tube differs from the vidicon design. The optical sensor is a photoemissive layer and integration by charge storage takes place on a thin glass or magnesium oxide membrane. A schematic drawing of the tube is shown in Fig. 5.[1] The optical image is projected onto the photocathode and the released photoelectrons are focused and accelerated towards the storage target. The secondary electrons generated from the glass membrane are drawn away by the screen, resulting in a positive charge pattern on the target. The resistivity of the target is in the order of 10^{12} ohm-centimeters, and the charge equalization between the two sides takes place in approximately one frame time. When the scanning beam sweeps the target, it brings each resolution element to the cathode potential. Electrons, which are returned from the target, enter an electron multiplier for signal amplification.

The purpose of this report is to describe a modified mode of operation of imaging tubes. This is the "preferential integration" (PI) mode of operation where optical signals are subjected to different integration times depending upon a

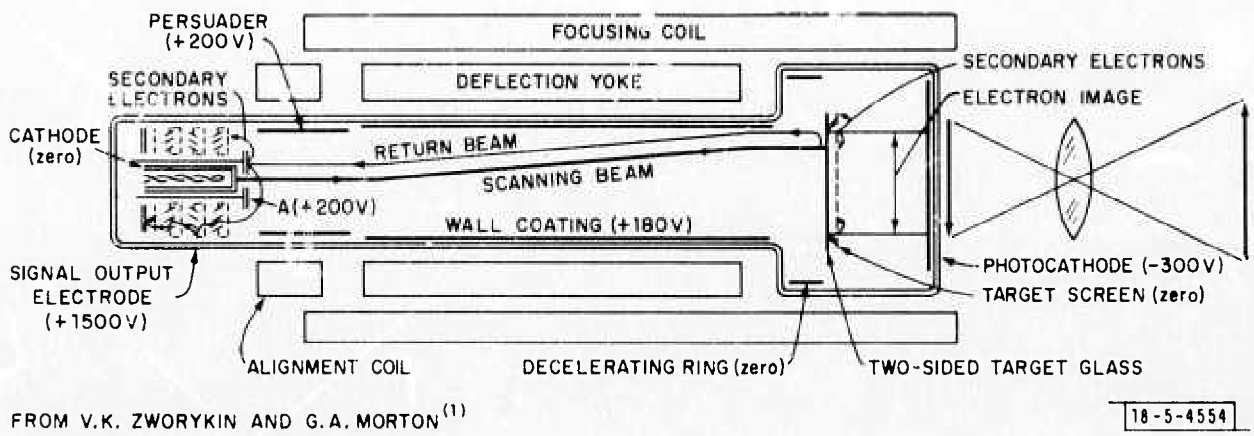


Fig. 5. Image orthicon.

prearranged program utilizing a storage tube system. This scheme permits preferential integration of low light level signals and suppression or even complete elimination of high intensity ones.

III. PRINCIPLES OF THE PREFERENTIAL INTEGRATION TECHNIQUE

In the previous section we stated that an electron beam in an imaging tube, scanning the target, replenishes the charge on each resolution element at equal time intervals. One can therefore say that the integration time of the optical signal for each resolution element is the same and is equal to the single frame duration. The integration time can be extended or shortened by the proper change in the system's frame rate. Another method of extending the integration time is the prevention of the neutralization of the charge stored on the tube's retina by turning "off" the electron beam for a predetermined number of frames. The resulting effect of both techniques is the same. Let us now assume that we are able to program the electron beam so that on preselected resolution elements we can turn the beam "off" for a certain number of frames, while for other resolution elements, the beam remains in the "on" state. On the selected resolution elements, which are not sensed by the beam each frame, the charge will start to build up, whereas no integration takes place on the remaining resolution elements. After a predetermined number of frames the beam switching sequence is stopped and the tube's beam current restored to its normal value. The accumulated charged pattern on the retina is read out providing a preferentially amplified output image.

A more detailed description of the system for preferential integration (PI) will be given in a later section. However, at this point let us explain how the programming of the electron beam is performed. The scene of interest is viewed by a TV camera and its output is recorded in a storage tube. The stored

image provides the programming memory for the modulation of the electron beam intensity of the imaging tube. During the operation of the system, the TV camera, which is still looking at the scene, and the storage system with the recorded image are synchronized, so that the electron beams in the two tubes dwell simultaneously on corresponding areas of the charge replicas of the optical image. Buffer electronics, placed between the storage tube and the TV camera, permit the imposition of a clip level on the signal output from the storage system. For output signals below the chosen level, the imaging tube's beam current is turned "off" and therefore, charge integration takes place. However, for signals above the preset level, the beam remains turned "on", preventing charge build up.

Until now we have discussed the simplest form of preferential integration. The scheme although useful, has some limitations and under certain conditions, the utilization of the so-called "beam starvation" technique is required. The solid curve on Fig. 4 represents a transfer function of a tube whose operational dynamic range is limited at low light levels by the system noise and the high irradiances are confined to the upper knee (point "B"). However, a prerequisite for the utilization of the full dynamic range of the tube is that the readout beam be able to neutralize all of the charge generated by the irradiance level at point "B". In conventional modes of operation of imaging tubes, the electron beam intensity is kept constant at this level, and the same is true for the beam in the "on" state during preferential integration as described above. Lowering the electron beam intensity below this level has a very interesting effect on the performance of imaging tubes. The intensity of the "starved beam" determines the maximum charge which can be delivered by the beam. Electrical charge concen-

trations below the beam's maximum capability are not differently effected because sufficient electrons exist in the beam for complete readout. However, a more highly charged resolution element is only partially discharged by the starved electron beam. The uncompensated charge residues from each frame will remain on the resolution element and will undergo integration. The replacement of the "on"-"off" states of the electron beam with more intensity levels in the PI technique permits a further expansion of the image tube's capabilities. The advantages of multiple electron beam intensities can be best illustrated in the following example.

Let us assume that we are trying to detect a very faint object in the presence of an optical background and other high intensity light sources. The simple PI technique would, for this application, be of only modest help. It is true that by setting the clip level properly we would be able to prevent integration of high level signals but amplification of the low light level images would be accompanied by a simultaneous growth of the background. As a matter of fact, if the background intensity is larger than the brightness of the signal looked for, which quite often is the case, then the integrated background signal could saturate the tube. The introduction into the PI technique of a starved readout beam provides the solution to the problem. The lowest level of the beam's intensity is kept at such a value that it is able to neutralize only charge levels corresponding to the background intensity. The control of the "starved beam" is done by a DC potential of the proper value applied to the tube's G1 grid. The introduction of the "starved beam" does not drastically change the routine of operation. In the integration method described in the beginning of this section, the electron beam's intensity fluctuated between zero and some maximum value. In the

modified version, which suppresses the background, we still have only two electron beam intensity levels. One is the low current level and the other is some maximum value. The PI technique with the background rejection feature is also able to prevent the charge build up caused by a uniform tube dark current. The PI methods described up to this point are not able to cope with spatially nonuniform backgrounds and/or tube dark current. A typical example of nonuniformities of this nature is the shading in the tube's output caused by spatial variations in the retina sensitivity and its dark current. However, even those nonuniform outputs can be suppressed by a method which will be described in the next section. At this point it should be clarified that our method of manipulation of the tube's electron beam by means of controlling the potential on the G1 grid is not the only available form of performing preferential integration. Another successful mode of operation is the modulation of the cathode to ground potential. In our work we have chosen the grid modulation because the retrace beam blanking was performed in the cathode circuit.

IV. SYSTEM DESCRIPTION

In this section a description of the system will be given with a detailed account of the functions of individual subsystems. A few examples of the application of the PI technique will illustrate its capabilities.

Figure 6 represents a block diagram of the integration system. The performance characteristics of the individual subsystems have to be properly chosen depending upon the nature of the optical image and the goal of the investigation.

A. TV Camera

Starting with the heart of the system, which is the TV camera, the selection of the imaging tube should be optimized

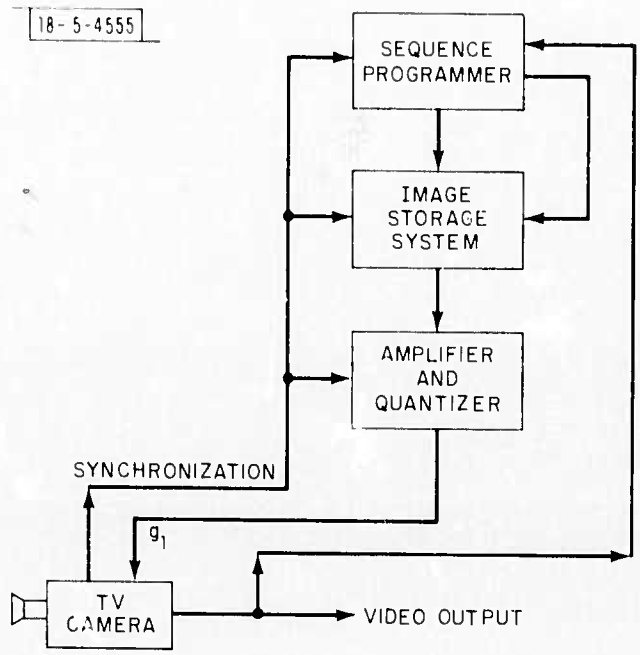


Fig. 6. Preferential integration system block diagram.

for a particular application. The tube's spectral response, sensitivity, resolution capability, frame and line rates, and mechanical construction among others are the parameters which should bear heavily on the proper choice. A large selection of low-light level (LLL) tubes is now available in the visible region of the optical spectrum. Starting with the different types of vidicons and image orthicons, the new additions to the imaging tube arsenal include the image isocon, SIT and ISIT. Additional image intensifiers can be used as optical pre-amplifiers, if an increase in threshold sensitivity of the system is required and some loss in resolution is tolerable. In some instances flexibility of operation has to be built into the camera for experimental determination of the best system performance.

The TV camera optics has to be individually designed for each application and for this reason will not be discussed in this report. However, it is important to realize that the choice of optics is a critical factor which can determine the success or failure of a project.

B. Storage System

The storage system acts as a high resolution, wide bandwidth programming memory which controls the image tube's beam intensity. The particular type of storage tube which we have used has a silicon target with narrow strips of silicon monoxide structure formed on its surface. Proper control of the target voltage permits three states of operation of the tube. During the write mode the target potential is set to approximately 300 volts, causing the electrons of the scanning beam to impinge on the silicon wafer with high energy. Secondary electrons, generated from the target area covered with the silicon monoxide, will leave a positive charge pattern corresponding in shape and intensity to the optical image seen by the TV

camera. The charge pattern can be preserved without distortion for a prolonged period of time. The read mode is obtained by scanning the tube's target with an electron beam when the retina voltage is dropped from +300 V to approximately +5 V. Under these conditions the scanning beam is able to sense, in a nondestructive way, the charge potential stored on the retina. Finally, the stored charge pattern can be erased by scanning the target with the electron beam when the retina potential is made approximately 20 V positive in relation to the cathode.

C. Amplifier and Quantizer

The function of the amplifier and quantizer (AQ) is to translate the output from the storage unit into the proper voltage value required by the G1 grid to regulate the electron beam intensity. The transfer function of the AQ, depending upon the application, is usually nonlinear with controllable clip levels for quantizing the input signals. In addition, if required, DC levels and pulses can be generated.

D. Sequence Programmer

The sequence programmer performs the duties of a "traffic controller" of the activities of the PI system. Its activity starts with the command sent to the storage system to record an image seen at this point in time by the TV camera. The next step is to clock the duration of integration and after a preset number of frames, to request the readout of the final output from the TV system for further handling. The sequencer is also responsible for requesting the AQ to generate at proper times a DC voltage and/or a pulse train.

All of the subsystems are driven in unison by the TV camera's synchronization generator. Buffer electronics compensate for geometrical distortions present in the storage and imaging tube's drives.

To further illustrate the performance of the PI system, a sample test run will be described whose goal is to search for a satellite during night time. A typical night time image of a section of the sky contains from a few hundred to a few thousand stars depending upon the FOV of the optics. Assuming that no planets are present in the system's FOV the intensity range of stars covers approximately four orders of magnitude. The brightness of the satellite may be very low so that even a LLLTV system would probably not be able to detect its presence under normal operational conditions. The night sky background intensity can exceed the satellite radiation by a factor of five. Depending upon the type of tube used, some additional complications can be encountered due to the tube's spatial nonuniformities in sensitivity and dark current value. In this example we will make provisions for the presence of a uniform dark current only. However, the problem of spatial nonuniformities of the dark current and tube's sensitivity will be treated separately. The primary function of the system, in this example, is to preferentially amplify low light level signals in the range of brightness expected for the satellite. On the other hand, images of bright stars should be suppressed or if possible even eliminated from the final readout. The build up, by integration, of the tube's dark current and of the optical background should also be prevented in order to preserve the full system's dynamic range for handling the required signals.

Figure 7 is a graphic presentation of the electronic processes which take place during preferential integration. Figure 7a is an "A" line readout taken from a single TV frame recorded in the storage system when the imaging tube is exposed to a night sky scene. The "dark level" voltage V_1 is the result of the summation of three independent potentials.

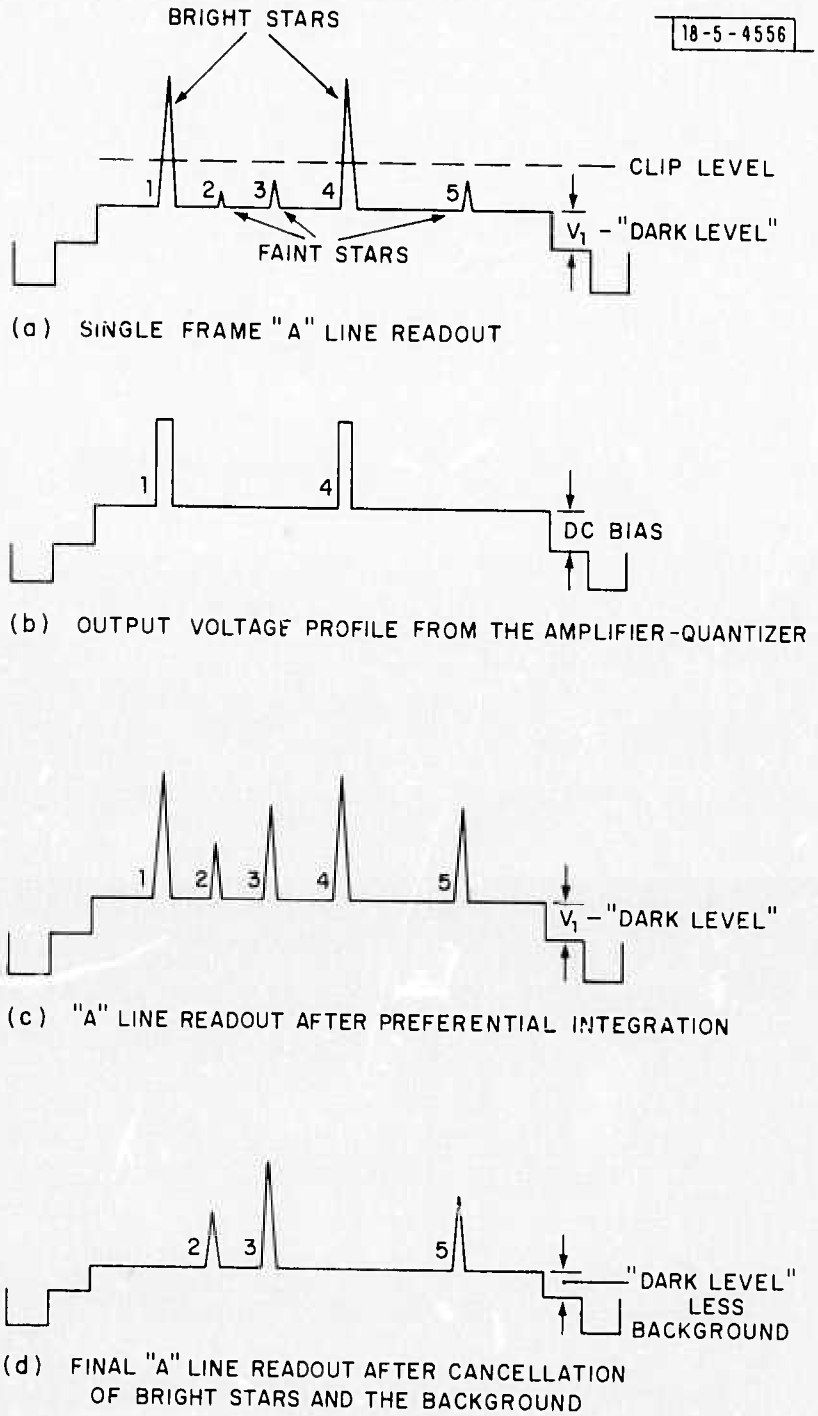


Fig. 7. Graphic presentation of electronics processes during preferential integration.

$$V_1 = V_p + V_D + V_B$$

V_p = Pedestal voltage needed for synchronization.

V_D = Output signal due to the tube's dark current.

V_B = Output signal due to the optical background.

The V_D and V_B voltages originate on the tube's sensing layer and therefore are subjected to integration. However, the pedestal voltage V_p is immune to integration because it is electronically generated in the TV camera.

The function of the clip level, which is generated in the AQ, is to sense the intensity of each individual star image and segregate them into two categories. The low intensity stars below the clip level, will be subjected to integration, whereas integration of brighter images will be prevented. The combined performance of the storage system and the AQ is presented in Fig. 7b. This is the potential synchronized with the "A" line readout in Fig. 7a, which is applied to the imaging tube's Gl grid. The output from the AQ consists of a constant potential V_{DC} and some pulses whose spatial position on the tube's retina coincides with the location of the bright stars. The value of the DC bias voltage is such that the tube's electron beam intensity is able to neutralize the charge leakage caused by the tube's dark current and the optical background only. The pulse amplitudes, applied to the Gl grid, "turn on" the electron beam with full intensity neutralizing the accumulated charge from the bright objects. The only signals which undergo integration are those whose amplitudes are between the V_{DC} and the clip level value. After the integration has been performed for the preselected number of frames, the sequencer turns "on" the electron beam to a nominal value for the final data readout. Figure 7c shows the

readout of an "A" line after integration. The two bright stars and the "dark level" remained at the same amplitude as for a single frame readout. However the low intensity images are amplified. The preferential amplification of low level intensity images, as essential as it is for some applications, can also have its troublesome side effects. The integration technique described above yields a presentation of the section of the sky with more visible stars than could be seen in the TV picture prior to amplification, thereby complicating the task of finding the satellite image. Partial relief can be gained by the incorporation of an optical shutter in front of the TV camera system accompanied by a modification in the programming sequence.

Let us assume that to obtain a suitable signal-to-noise ratio of the satellite image, integration of "n" frames is required. At the end of frame number "n", an optical shutter blocks the light from entering the imaging tube but the potential on the G1 grid is still modulated in the same mode as during regular integration. The beam scanning the tube's retina during the n + 1 frame will discharge the images of the bright stars and the "dark level," leaving the charges of other stars untouched. With the optical shutter still closed, during the n + 2 frame the full electron beam is turned "on" and the TV readout will contain only the intensified images of low light level stars including the satellite. Even after this technique of lowering the number of stars in the TV output, (see Fig. 7d), detection of the satellite can be difficult. Relative motion of the satellite in relation to the fixed star background can be utilized for this purpose. A subtraction technique of two images of the same sky section taken at different times could yield a cancellation of the fixed stars, leaving only the satellite visible. Laboratory experimental

work seems to justify this approach.

Till now we have considered a PI system which operated with an imaging tube having a uniform dark current and operating under uniform background conditions. However, imaging tubes in the vidicon family are known to have a so-called "shading" problem caused by nonuniformities in the retina material or resulting from the non-perpendicular electron beam landing on the sensing layer. The presence of those nonuniformities requires a modification to be made in the AQ capabilities.

Figure 8 shows an "A" line readout from a vidicon tube with "shading" and images of stars of various intensities superimposed over the "dark level." During the preferential integration process the "shading" is compensated by an analog signal whose shape approaches the "dark level" outline. In the preferential integration of signals described previously, only two potential levels were generated by the AQ. A constant DC potential for suppression of the uniform "dark level" and pulses for suppression of signals above the clip level. In its modified version, the AQ still generates pulses for signals above the clip level. However, the output from the storage unit of the "dark level" is converted into variable potentials which are necessary to compensate for the image tube "shading." The typical transfer function of the modified AQ is shown in Fig. 9. The input voltage corresponding to the value "K" is the preset clip level for signal amplitudes above which the electron beam of the imaging tube is fully turned "on" and therefore the integration is prevented. For practical reasons complete compensation of the "shading" is not attempted during each frame. It will follow the dotted line shown in Fig. 8, leaving a safety margin to prevent occasional overshoots of the tube's beam current. However, this safety margin will cause some amplification of the dark

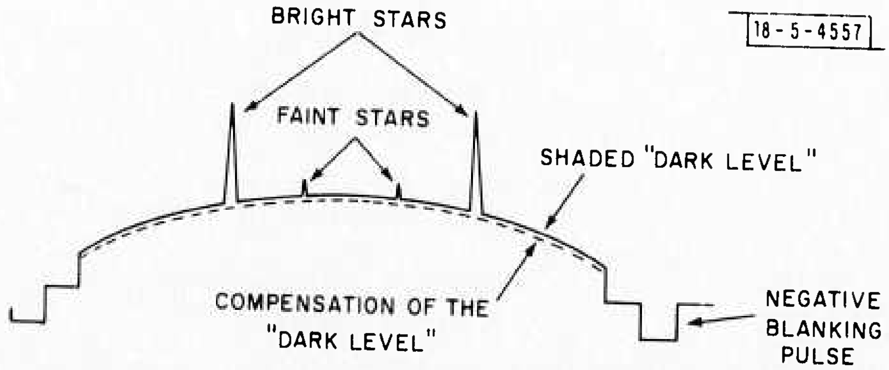


Fig. 8. "A" line readout with shaded "dark level".

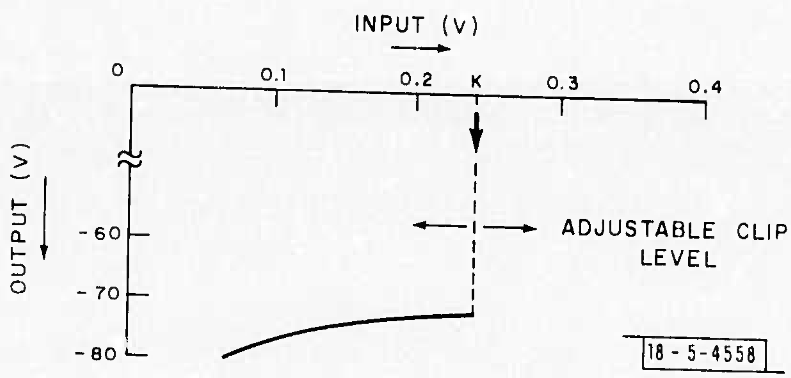


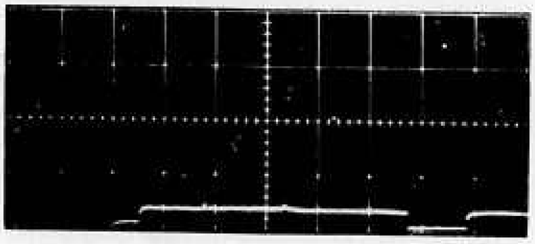
Fig. 9. Transfer function of the amplifier-quantizer.

level proportional to the number of integration frames. Consequently, a compensation arrangement is incorporated into the AQ which applies a preset DC potential, after a predetermined number of frames, to the imaging tube's G1 grid bringing down the accumulated "dark level" charge to a tolerable value.

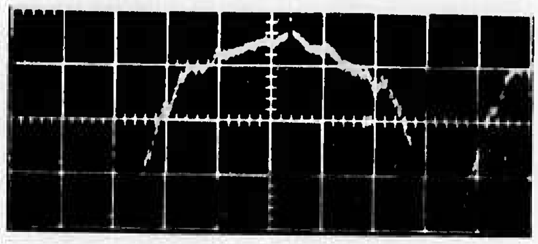
V. MEASUREMENTS

The measurements reported here illustrate the performance of the preferential integration system. Figure 10a represents an "A" line readout from a conventionally operated TV camera. The pip in the center of the line is an optically unresolved image of a point source. The tube used in these measurements was a silicon diode type vidicon. The signal to peak-to-peak noise ratio as seen from this figure is less than unity. Figure 10b shows the tube output after eight frames of nondiscriminating integration. In this test the electron beam was turned "off" for a period of eight frames and during the 9th frame the full beam was turned "on" again for data readout. The result of the nondiscriminating integration yields an improved signal to noise ratio but at the same time the tube's dark current takes up a large part of the tube's dynamic range. Figure 10c is the tube's output after eight frames of preferential integration. During the integration period the starved beam current was kept at such a value that it was able to compensate for the dark current only, without preventing the integration of the point source image. The structure seen on the "A" line readout outside of the image is caused by the amplification of previously inflicted burns in the tube's retina. The signal to noise ratio after PI is of the order of eight.

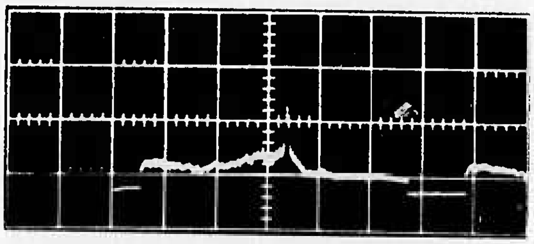
An example of a more elaborate test of preferential integration is shown in Fig. 11. Here the dark current and



(a) SINGLE FRAME READOUT



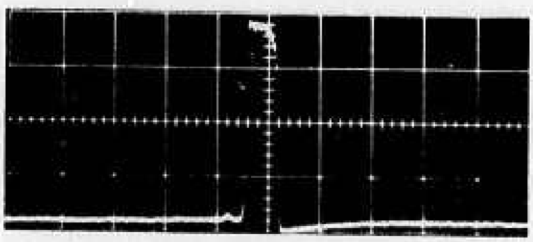
(b) READOUT AFTER 8 FRAMES OF INTEGRATION



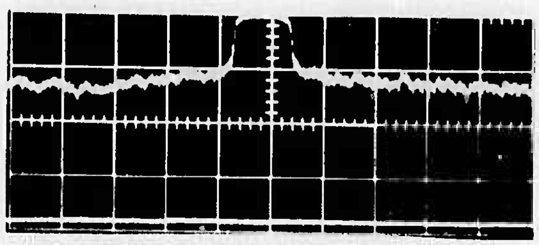
(c) READOUT AFTER 8 FRAMES OF PREFERENTIAL INTEGRATION

-5-4559

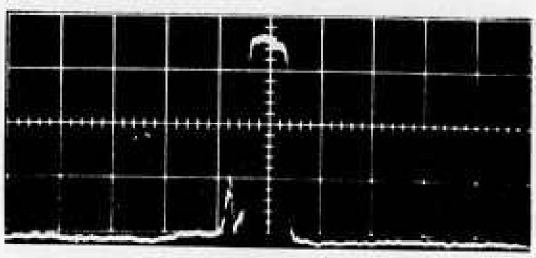
Fig. 10. Signal integration with cancellation of "dark level".



(a) SINGLE FRAME READOUT



(b) READOUT AFTER 8 FRAMES OF INTEGRATION



(c) READOUT AFTER 8 FRAMES OF PREFERENTIAL INTEGRATION OF THE SMALL SIGNAL ONLY

-5-4560

Fig. 11. Preferential integration.

the bright images are suppressed and only the weak signals are integrated. In these measurements, the optical image consisted of two point sources. A low intensity one shown in Fig. 11a as the small pip and the other, 10^3 times brighter, is shown as the big pulse. Figure 11b shows the results of non-discriminating integration for a period of eight frames. The dark current is drastically increased and the high intensity signal did spread, camouflaging the image of the low light level point source. In Fig. 11c the results of preferential integration are illustrated. The integration of the dark current was prevented by the presence of a continuous, low value beam current. The preferential integration of the low level signal only, without amplification of the high signal, was performed by the proper modulation of the beam current as described in the preceding sections.

VI. CONCLUSIONS

A technique has been described which enhances the sensitivity of electron beam scanning tubes by a preferential integration scheme.

Low light level signals in a preselected range are amplified, whereas electrical outputs from bright images, tube dark current, and background are suppressed or eliminated. This unique integration technique also advantageously influences some other performance characteristics of imaging tubes. The transfer function represented by the right hand curve in Fig. 12 has a useful dynamic range of approximately two orders of magnitude. However the same tube's transfer function, when operated in the preferential integration mode, has an extended dynamic range by over one magnitude. The extension of the dynamic range and the amplification of signals below the clip level, in this particular case, required 30 frames of

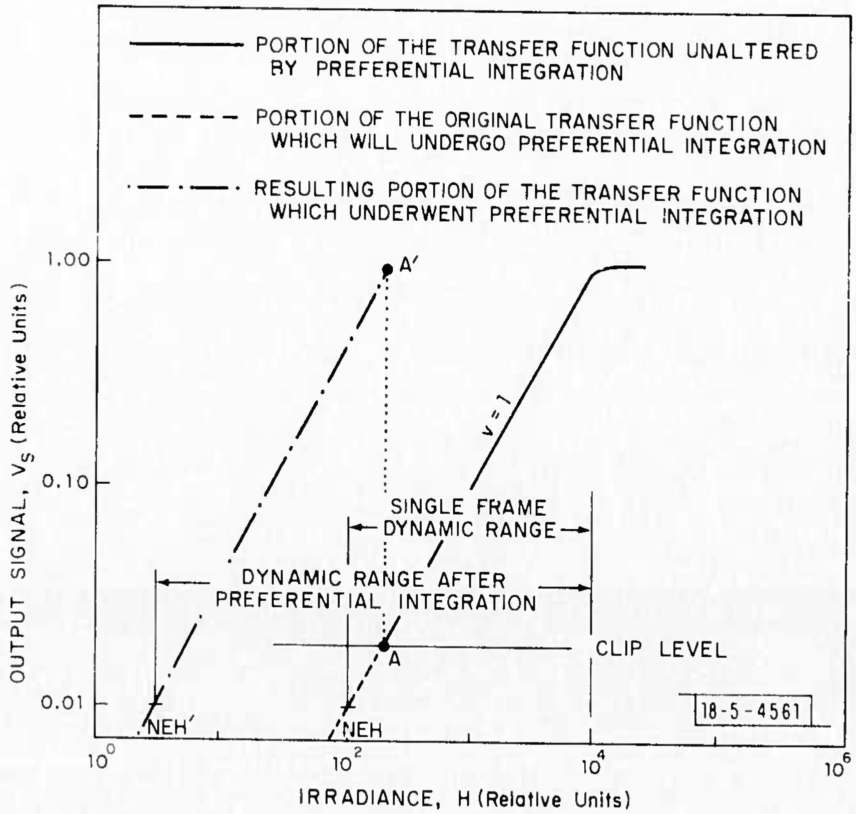


Fig. 12. Transfer function of a "direct readout" silicon vidicon tube operated in the preferential integration mode.

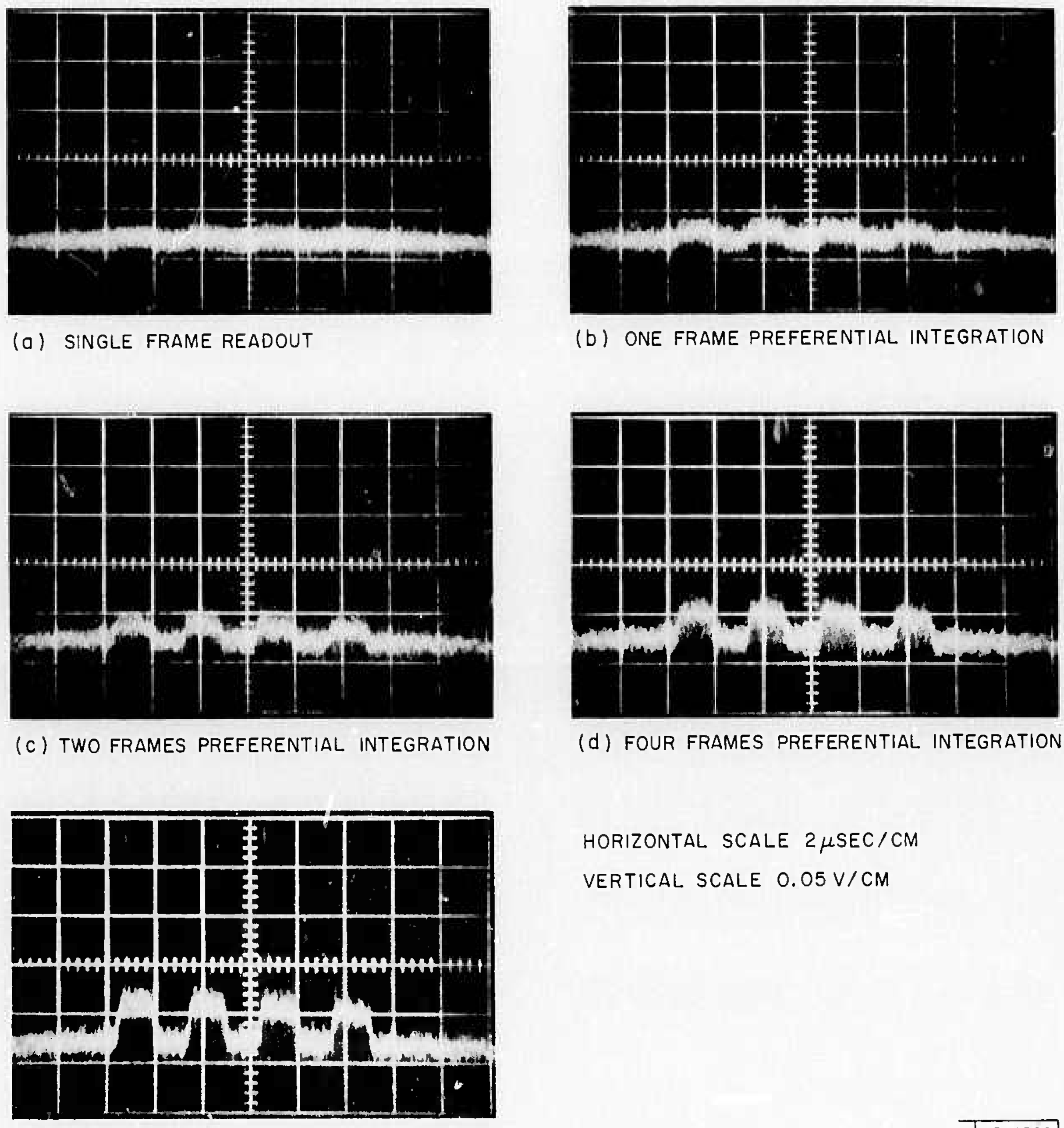
preferential integration. The signal-to-noise ratio of low light level signals is also improved by integration. The optical signal-to-noise ratio is proportional to $\sqrt{n}$ (where "n" is the number of photons collected by the tube's sensor) and this value increases with exposure. The improvement in the electrical signal-to-noise ratio depends on the tube design. For "direct readout" beam tubes with a transfer function slope of unity ($\gamma = 1$), the signal-to-noise ratio improves linearly with integration. For "return beam" tubes the improvement is less dramatic because the signal-to-noise ratio is proportional to $\sqrt{V_s}$. Using the PI technique on a silicon type vidicon, we were able to extract and further amplify signals starting with a signal to peak-to-peak noise ratio of 0.05.

The preferential integration also has a favorable effect upon the resolution and contrast quality of the output image. This is a direct consequence of the improvement in the signal-to-noise ratio mentioned above, and the amplification of the signals with a simultaneous suppression of "dark levels." Figure 13 illustrates the improvement in the image modulation resulting from the PI technique.

Figure 13a is an "A" line readout from a TV system operated in a standard mode. The other pictures in Fig. 13, namely b, c, d, and e, are showing the results from 1, 2, 4, and 8 frames of preferential integration respectively.

ACKNOWLEDGMENTS

The authors wish to thank Dr. J. O. Dimmock and T. M. Quist for their suggestions, support and guidance. The assistance of H. L. Ziegler in circuitry development is highly appreciated.



(a) SINGLE FRAME READOUT

(b) ONE FRAME PREFERENTIAL INTEGRATION

(c) TWO FRAMES PREFERENTIAL INTEGRATION

(d) FOUR FRAMES PREFERENTIAL INTEGRATION

(e) EIGHT FRAMES PREFERENTIAL INTEGRATION

Fig. 13. Preferential integration of a bar-pattern image.

REFERENCES

1. V. K. Zworykin and G. A. Morton, Television, 2nd Ed. (John Wiley & Sons, Inc., New York, 1954).

2. L. M. Biberman and S. Nudelman, Photoelectronic Imaging Devices, Vol. 1 and 2 (Plenum Press, New York, 1971).

3. B. Kazan and M. Knoll, Electronic Image Storage (Academic Press, New York, 1968).

4. J. D. McGee and D. McMullan, Photo-Electronic Image Devices, Vol. 22A (Academic Press, New York, 1966).

5. L. M. Biberman, et al., "Low-Light-Level Devices: A Designers' Manual", IDA R-169 (August 1971).